Thermal Management for Electrified Aircraft

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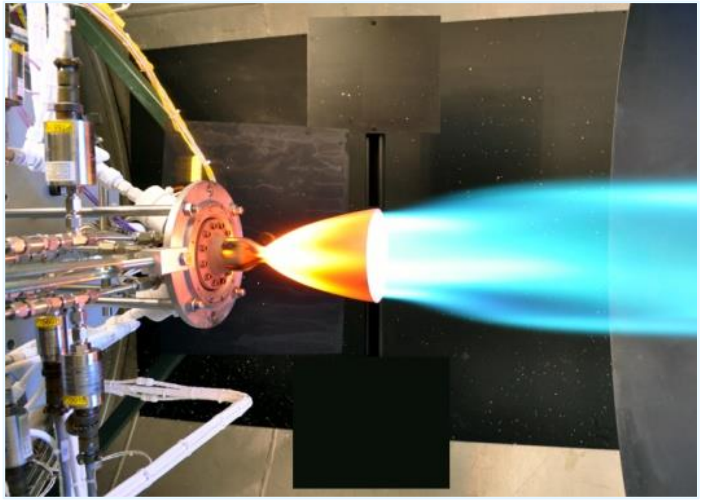
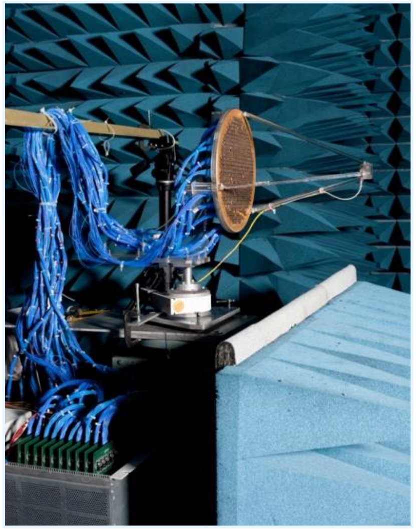
NASA Glenn Research Center Core Competencies

Air-Breathing Propulsion



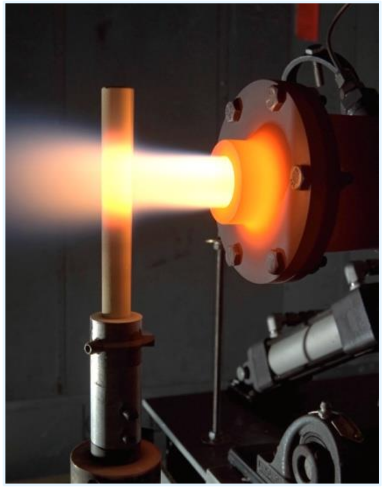
In-Space Propulsion and
Cryogenic Fluids Management

Physical Sciences and
Biomedical Technologies in Space



Communications
Technology
and Development

Power, Energy
Storage and
Conversion



Materials and
Structures
for Extreme
Environments

NASA Aeronautics Strategic Thrusts

Safe, Efficient Growth in Global Operations
- Achieve safe, scalable, routine, high-tempo airspace access for all users

Innovation in Commercial Supersonic Aircraft
- Achieve practical, affordable commercial supersonic air transport

Ultra-Efficient Subsonic Transports
- Realize revolutionary improvements in economics and environmental performance for subsonic transports with opportunities to transition to alternative propulsion and energy

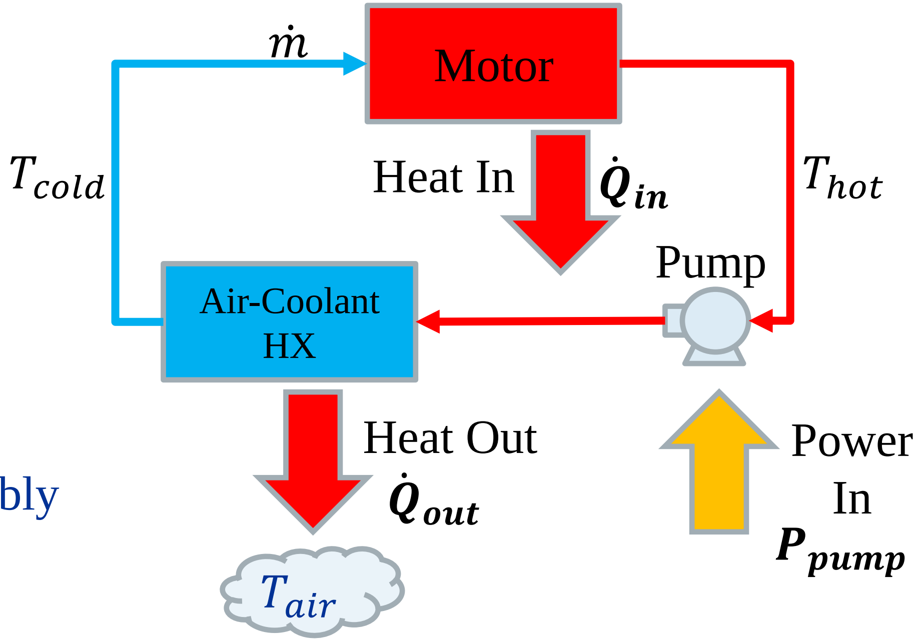
Safe, Quiet, and Affordable Vertical Lift Air Vehicles
- Realize extensive use of vertical lift vehicles for transportation and services including new missions and markets

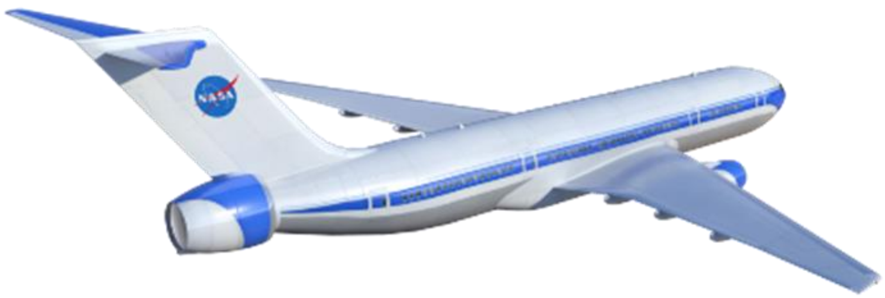
In-Time System-Wide Safety Assurance
- Predict, detect and mitigate emerging safety risks throughout aviation systems and operations

Assured Autonomy for Aviation Transformation
- Safely implement autonomy in aviation applications

Electric Aircraft Thermal Management System (TMS) Challenges

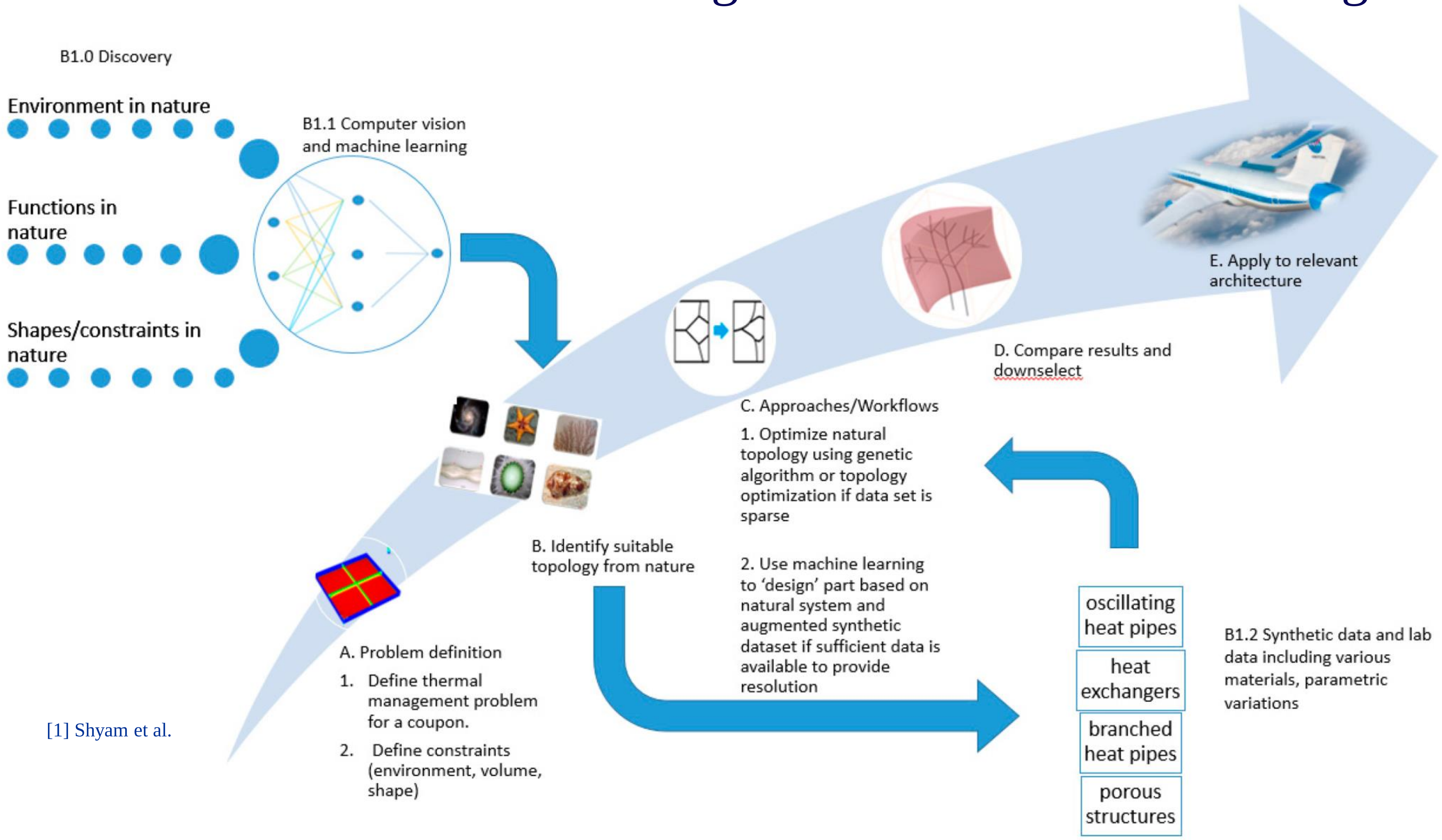
- **Higher-rated motors require more aggressive cooling approaches**($\uparrow \dot{Q}_{in}$)
  - Require more novel and invasive techniques($\uparrow$ *complexity*)
- **Large amounts of low-quality heat are generated**
  - Low efficiency components (< ~98%), electronics ($\uparrow \dot{Q}_{in}$)
  - Low temperature limits: $60℃ \leq T_{component} \leq 200℃$ ($\downarrow \Delta T_{component}$)
  - 10 MW system with 2 % inefficiency = 200 kW heat to be managed
- **Component reliability is considerably affected by temperature**
  - Every 10℃ decrease in component temperature can extend life considerably
  - But this causes the TMS to be more massive and power consuming
- **Different vehicle configurations present different and variable challenges**
  - Varying & intense load profile over mission
  - Different flight profiles will determine limits in rejection
  - Physical vehicle constraints may limit components to small spaces, which may lead to greater potential for overheating and higher TMS complexity





Credit: Susan Johnson and Hashmatullah Hasseeb (NASA GRC)

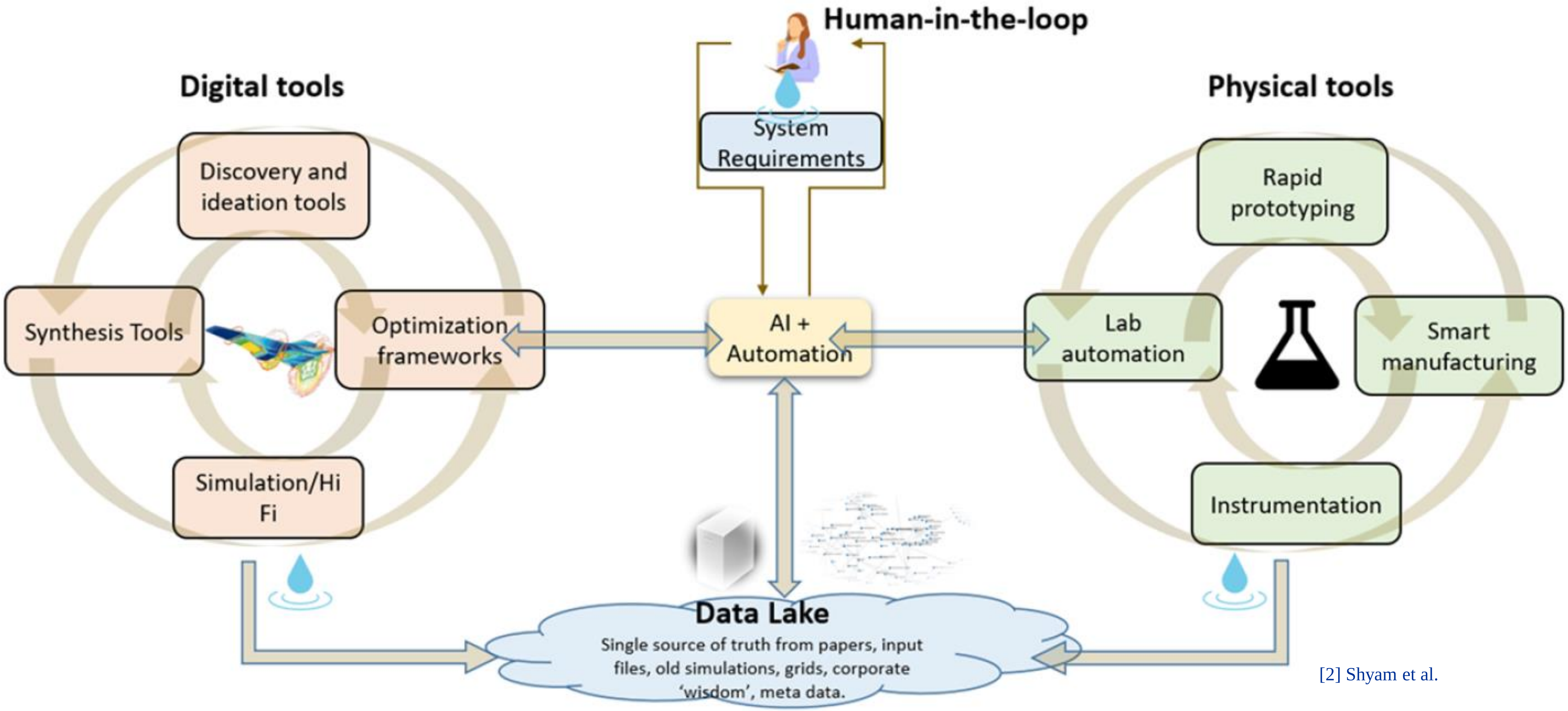
Workflow for Thermal Design with AI/Machine Learning



[1] Shyam et al.

[1] Shyam, Vikram, Lauren Friend, Brian Whiteaker, Nicholas Bense, Jonathan Dowdall, Bishoy Boktor, Manju Johny, Isaias Reyes, Angeera Naser, Nikhitha Sakhamuri, Victoria Kravets, Alexandra Calvin, Kaylee Gabus, Delonte Goodman, Herbert Schilling, Calvin Robinson, Robert O. Reid II, and Colleen Unsworth. 2019. "PeTaL (Periodic Table of Life) and Physiomimetics" Designs 3, no. 3: 43. https://doi.org/10.3390/designs3030043

IDEAS – Intelligent Design and Engineering of Aerospace Systems



[2] Shyam et al.

[2] Vikram Shyam, Paht Juangphanich, Ezra O. McNichols, Brooke Weborg, Herbert Schilling, Calvin Robinson, Kenji Miki, Manan A. Vyas, Arman Mirhashemi, Joshua Stuckner, Laura Evans, Samaun Nili and Ajay Misra. "IDEAS (Intelligent Design and Engineering of Aerospace Systems)," AIAA 2022-1043. AIAA SCITECH 2022 Forum. January 2022.

Leveraging Generative Design for Heat Exchangers

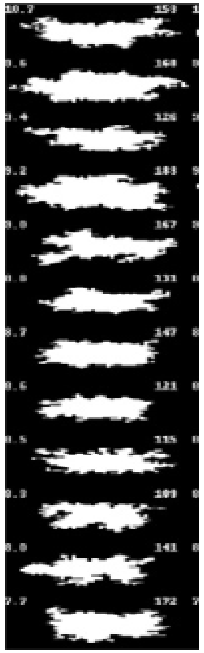
Initial Geometry/Space and BCs

Generative Design "Blackbox"

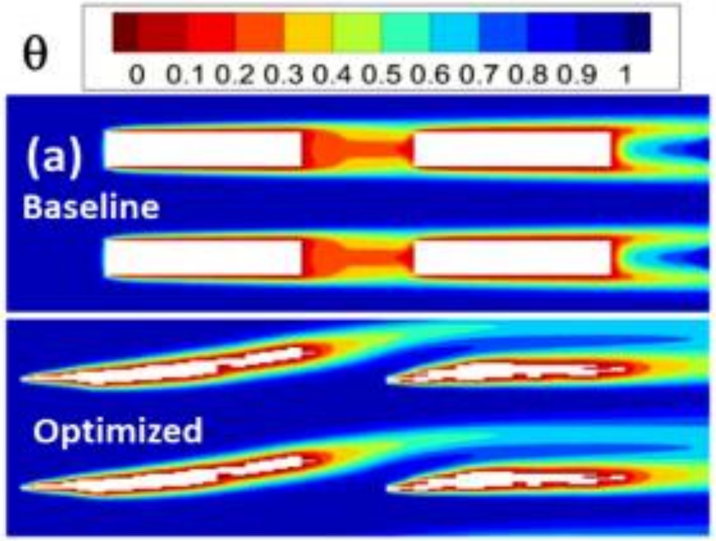
Tools for:
- Physics evaluation (CFD/FEA and/or surrogate models)
- Geometry generation/mutation (parameterized and/or voxel-based)

Outputs/Designs

- Heat Exchanger "1"
- Heat Exchanger "2"
- Heat Exchanger "3"
- •
- •
- •
- Heat Exchanger "N"



[3] Mekki et al.



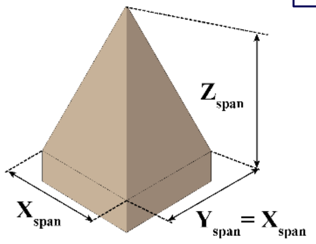
[3] Mekki et al.

[3] Bashir S. Mekki, Joshua Langer, Stephen Lynch, "Genetic algorithm based topology optimization of heat exchanger fins used in aerospace applications", International Journal of Heat and Mass Transfer, Volume 170, 2021, 121002, ISSN 0017-9310, https://doi.org/10.1016/j.ijheatmasstransfer.2021.121002.

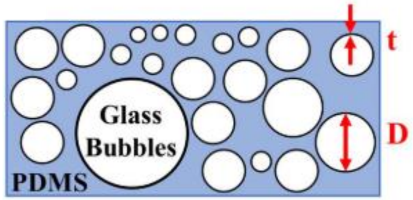
Tunable Radiation with Surface Microstructures

<u>Goal:</u> Use machine learning to analyze and design surface microstructures to change the wavelength of reflection and emission from a surface

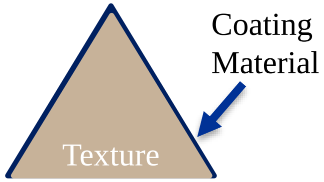
Microstructures



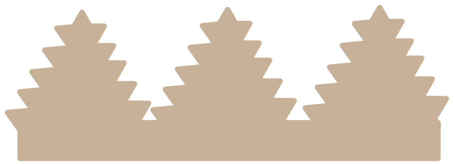
Micropyramids



Microspheres

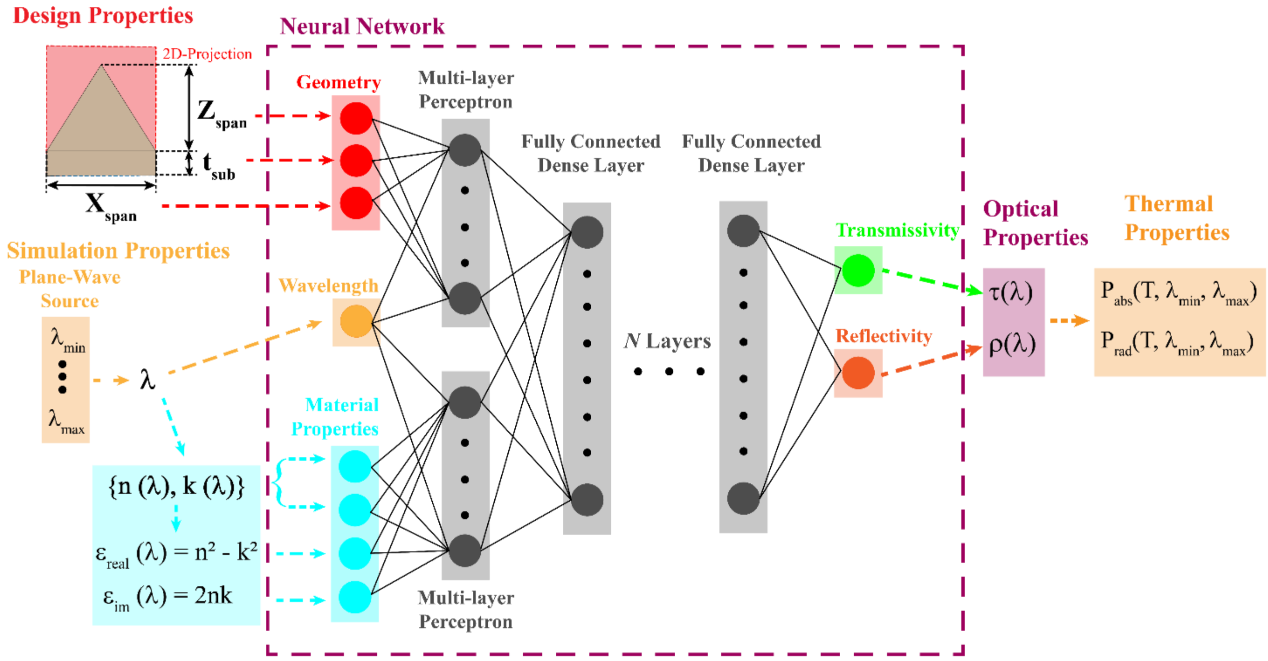


Multilayer/Coated

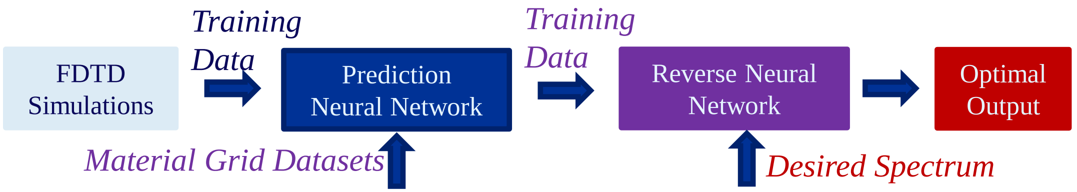


Hierarchically Textured

Neural Network for Analysis

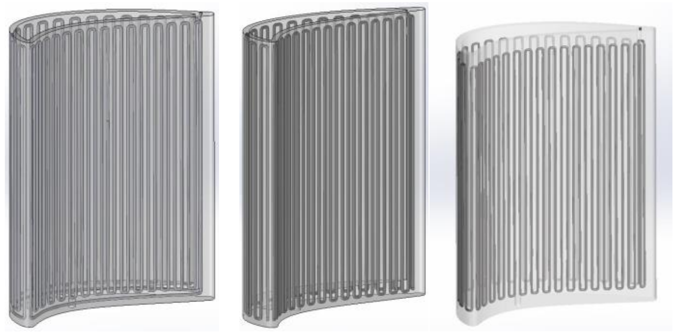


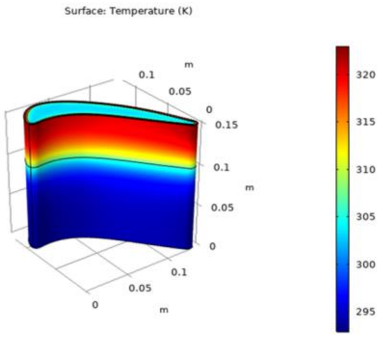
Design Process



Multifunctional Heat Pipe Airfoils

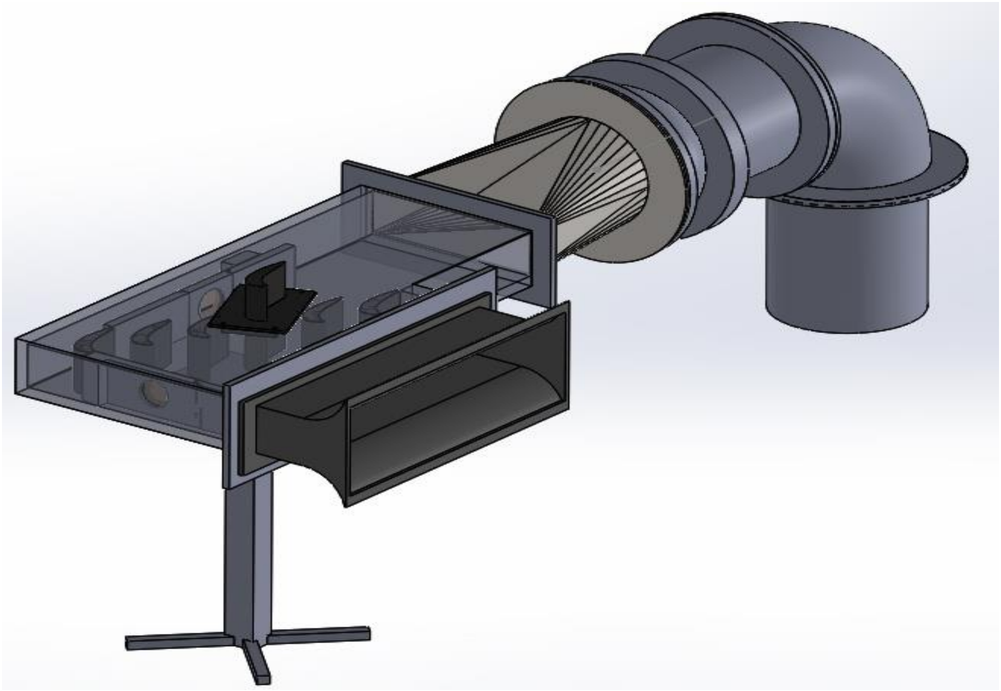
Design and Analysis Tool Development





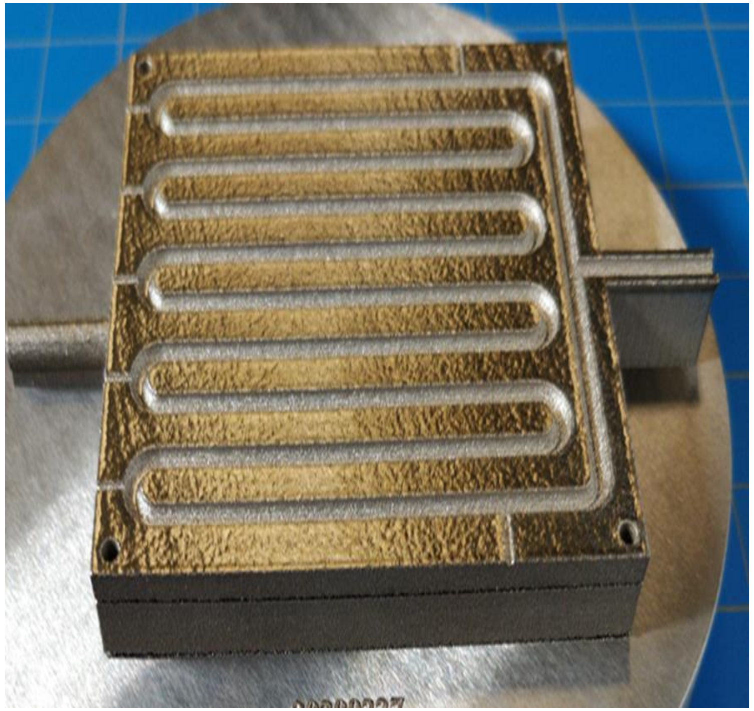
Tools consist of:
- 0-D for Initial Sizing (thermal resistance network)
- 3-D Multiphysics (ignoring external aero)
- 3-D Multiphysics (coupling with external aero)

Low Temperature Aero/Thermal Testing



Main Points:
- Goal of tests are to assess performance/stability, and to compare to 3-D Multiphysics models (both levels of fidelity)
- For OHP designs, more emphasis on stability rather than comparison to tools

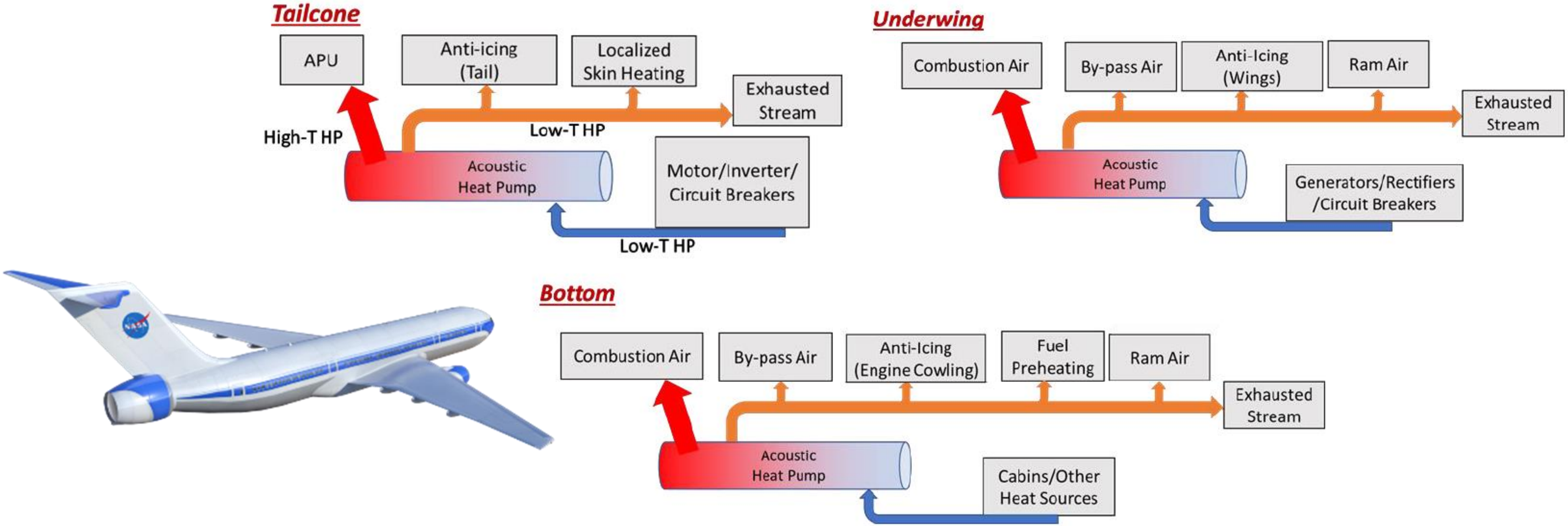
High Temperature Coupon Testing



Main Points:
- Data for high temperature OHPs is scarce. Only 1 published paper with this data (in 2020)

Thermal Management System with Solid-State Thermal Switching

Goal: Use heat pipes to passively (without electronic controls) redirect heat between multiple sources/sinks on the aircraft.



[4] Diebold et al.

[4] Jeff Diebold, Calin Tarau, Kuan-Lin Lee, William Anderson and Rodger W. Dyson. "Electric Aircraft Thermal Management Using a Two-Phase Heat Transport System with Solid-State Thermal Switching Capability," AIAA 2021-3334. AIAA Propulsion and Energy 2021 Forum. August 2021.

What is needed?

- Design and Analysis Tools
  - Leveraging AI/Machine Learning to expedite the design/analysis process
  - Leveraging AI/ML to expand the design space
- Advanced Heat Exchanger Concepts
  - High thermal performance
  - Minimal weight
- Additively Manufactured Heat Pipes
  - Innovative wick designs, implemented through additive, may lead to an increase in performance and limitations
  - Multifunctional design
- Oscillating Heat Pipes
  - Predictive modeling of this is extremely difficult and time consuming. This is the largest barrier for this technology to be implemented on a wider scale.
- Phase Change Materials

Previous NASA Funding Opportunities for Electrified Aircraft TMS

- **SBIR/STTR Program**
  - Numerous awards (~5 or 6) each year for Electrified Aircraft
  - Thermal is crosscutting
- **NASA Fellowship Program**
  - 3 Fully-funded PhD Students
    - “Radiative Thermal Control by Novel Selective Emitter Materials” – Jonathan Sullivan (University of California Irvine)
    - “ Topology Optimization of Multifunctional Thermal Management Systems for Aerospace Applications” – Bashir Mekki (Penn State University)
    - “Development of Ultra-Lightweight Acoustic Absorption Material/Structural System for Acoustic Management” – Bharath Kenchappa (North Carolina A&T State University)
- **NASA GRC Independent Research and Development (IRAD) and Center Innovation Fund (CIF) Programs**
  - PI must be a NASA Civil Servant
  - Teaming with Industry/Academia is encouraged
  - Generally smaller funds than SBIR/STTR program

Links for NASA Calls for Proposal

- NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES)
  - https://nspires.nasaprs.com
- Small Business Innovation Research (SBIR) & Small Business Technology Transfer (STTR) Program
  - https://sbir.nasa.gov/